MINERAL RESOURCES BRANCH

Pyrophyllite Occurrences in the Coxheath area, Cape Breton Island

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1.0 Introduction

Nova Scotia produces over $250 million worth of industrial minerals and structural materials annually. Because of the importance of non-metal mining as a foundation industry in Nova Scotia, the Nova Scotia Department of Natural Resources (NSDNR) continues to evaluate the province's mineral resources with the long term goal of maintaining and increasing mineral development and employment in Nova Scotia. As part of this effort, review of NSDNR Assessment Reports and publications identified deposits of the mineral pyrophyllite near Coxheath, Cape Breton County. The pyrophyllite occurrence has been known since the late 1800s, however it was only recognized as a 'fire clay'. Greig (1943) identified the 'fire clay' as actually being the mineral pyrophyllite. Since the early 1900s the occurrence and/or economic significance of pyrophyllite as an industrial commodity has been forgotten. Lynch and Ortega (1997) mention pyrophyllic alteration and mapped occurrences in the Coxheath Cu-Mo-Au deposit area. During the fall of 2002, NSDNR staff located one of the main pyrophyllite bodies, and conducted trenching, sampling and geochemical analysis.

This report focuses on the location, extent and industrial mineral potential of the pyrophyllite deposit(s). The relationship between the occurrence of pyrophyllite and previously described Cu-Mo-Au mineralization at the Coxheath deposit (Kontak et al., 2001; DeWolfe, 2001) and a complete ore model describing the Coxheath plutonic-volcanic belt and associated porphyry-epithermal mineralized system is described by Kontak et al. (2003).

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2.0 Commodity Background

Pyrophyllite is a phyllosilicate with the chemical formula $Al_2Si_4O_{12}(OH)_2$, and in its pure form is composed of 28.3% Al_2O_3, 66.7% SiO_2 and 5% H_2O. It has a pearly luster, commonly a white, apple-green, grey or brown colour, and a hardness of 1-2; however, the hardness typically is deceptive in the field as the mineral is often impure, with associated quartz increasing the rock's apparent hardness (vs. the pure mineral phase).

The commercial applications of pyrophyllite are numerous and varied. The following applications are summarized from Harben (1999). Pyrophyllite finds uses as a refractory mineral, where at a temperature of 1,200°C it decomposes to cristobalite and mullite with a corresponding increase in hardness to 7-8. It has numerous beneficial technical properties such as resistance to corrosion from molten metals, low thermal conductivity, and low coefficient of expansion. It finds major usage as a substitute for silica and feldspar in ceramic applications, particularly the manufacture of floor and wall tile. As a fine-ground powder or a liquid slurry it acts as an effective carrier for fungicide, insecticide, herbicide and fertilizer. White fine-ground grades are also used a s fillers in wallboard, texture paint, plastics, paper, rubber and vinyl tiles.

Pyrophyllite is typically mined by open-pit methods and ore processing is minimal. Grinding reduces the soft pyrophyllite to fine grain sizes that can be classified by air classification. Heavy media separation may be used to remove trace heavy minerals, and in deposits where there are significant amounts of free silica a simple froth flotation can be used to float the pyrophyllite (Harben, and Kuzvart, 1997).

Approximately 80% of world production (2.2 million tons) comes from Japan and South Korea. The remainder is produced by Brazil, India, USA, Pakistan and Thailand. Canada's only producing mine was on the Avalon Peninsula of Newfoundland at the Manuals Mine. It only recently closed, but while in operation produced up to 40,000 tons/year of high-grade pyrophyllite product for a captive tile plant in the USA.

Pyrophyllite is a relatively high value industrial mineral with prices dependent on grade, which

is in turn generally controlled by the Al_2O_3 content and in particular the occurrence of secondary mineral phases creating a natural blend with various properties. The properties controlled by the mineral blend determine the most suitable end use and thus prices vary based on application. For example, Korean ceramic grade (15% - 19% Al_2O_3) ranges from US$27 to US$44 per tonne FOB; Korean fibre glass grade (18% - 21% Al_2O_3) ranges from US$59 to US $65 per tonne FOB; Korean clay filler grade (21% - 27% Al_2O_3) ranges from US$110 to US $150 per tonne FOB; and Australian filler grade (28.2% Al_2O_3) is quoted at US$342 per tonne FOB. All prices are quoted from Industrial Minerals Magazine, April 2003.

3.0 Regional Geological Setting

The Coxheath plutonic-volcanic belt (CPVB) occurs in eastern Cape Breton Island and is the westernmost of several Late Precambrian (Hadrynian) volcanic-plutonic belts that together form part of the Avalon Terrane of the Canadian Appalachians. These belts, from the Atlantic Coastline in the east to the Bras d'Or Lakes in the west, are the Coastal Belt (570 Ma), Stirling Belt (680 Ma), Sporting Mountain Belt (620 Ma), East Bay Hills Belt (620 Ma), and Coxheath Belt (620 Ma). Based on the petrological features of the igneous rock suites, these belts are considered to represent the remnants of once extensive continental margin plutonic-volcanic arcs that formed above ancient, westward-dipping subduction zones (e.g. Keppie and Dostal, 1991). Thus, these belts may be considered ancient analogues of the Andean-type continental margin tectonics where numerous porphyry deposits are located. The rocks form basement blocks that define prominent topographic highs surrounded by younger Cambrian to Carboniferous sedimentary rocks. Within these rocks are variable amounts of polymetallic mineralization that correlate in terms of metal endowment and style with porphyry (e.g., Coxheath) and massive sulphide (VHMS; Stirling) types of deposits.

The Coxheath Group of the CPVB underlies the Coxheath Hills and Spruce Brook areas on the north side of East Bay, and is divided into three lithological units of basaltic, andesitic and rhyolitic composition. Each unit contains both flows and fragmental rocks, but epiclastic sedimentary rocks are rare. The volcanic rocks were intruded by dioritic to granitic rocks. The rocks have been metamorphosed to greenschist or sub-greenschist facies and have a weak,

northeast-trending fabric with steep dips. Poles to primary layering in the volcanic rocks suggest folding about a southwest plunging fold. The volcanic and plutonic rocks are overlain unconformably by Cambrian to Carboniferous sedimentary rocks.

4.0 Geological Features of Pyrophyllite-bearing Altered Volcanic Rocks of the Coxheath Area

A sequence of felsic volcanic rocks, part of the Coxheath Plutonic-Volcanic Belt (CPVB), occur approximately 4-6 km northeast of the Coxheath deposit area (Figure 1). These rocks contain deposits of pyrophyllite developed within structural zones. Their occurrence, distribution, petrographic features and geochemistry are discussed in the following sections.

4.1 Occurrence and Distribution of the Pyrophyllite Rocks

The distribution of pyrophyllite occurrences is shown in Figure 1, modified from O'Reilly (2003) and based on mapping by P. Finck during the fall of 2002. Seventeen separate occurrences were mapped by Mijgley (1917); however, because of severe distortion and uncertainty in map orientation, these occurrences are not plotted. Only one occurrence, the site of a former small quarry, was located by NSDNR staff in 2002. This occurrence was formerly quarried in the late 1800s - early 1900s as a base for the manufacture of refractory brick. In the fall of 2002 trenching of this area was carried out by NSDNR in order to determine the extent of the pyrophyllite, assess its contact relationships to the surrounding rocks, and obtain samples for analysis. Trenching and location of additional outcrops in the former quarry area indicate the pyrophyllite zone: (1) is oriented north - northwest, (2) has both gradational and abrupt contacts with the surrounding felsic volcanics, and (3) defines a zone approximately 15 m wide and >150 m in strike length. The vertical dimension remains undefined, but the literature indicates that similar zones mined globally are vertically extensive and continue beyond the economic cutoff for the ore bodies. In outcrop the pyrophyllite-rich zone is not readily recognized as being significant despite the fact that it is composed predominantly of this valuable industrial mineral. However, once recognized, the extent of the zone is easily determined because the outcrops are characterized by their light buff to pale pink colour and

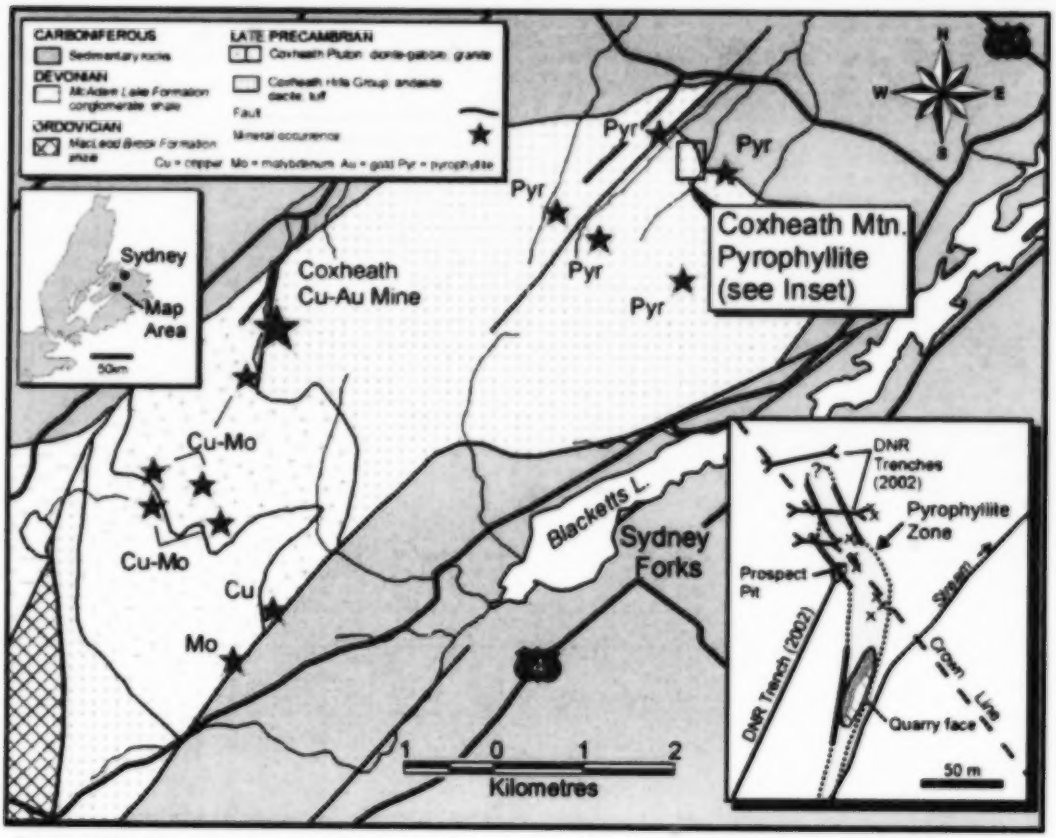


Figure 1. *Regional geological setting of the Coxheath area showing the location of the Coxheath deposit and related mineralized zones and the areas of pyrophyllite mineralization (after O'Reilly, 2003). Inset box is enlargement of the area of trenching done by NSDNR in fall of 2002.*

massive texture (Figure 2a). The rock has a well developed, penetrative fabric and preferentially breaks along this direction. In addition, the pyrophyllite-rich zone in this particular area defines local topographic highs (on an outcrop scale) of north - northwest orientation. Where the contact is fault-controlled the pyrophyllite stands in relief surrounded by deeply altered and weathered felsic volcanic rock that is easily removed with an excavator.

We emphasize that previous workers had mapped out about 17 other zones of pyrophyllite in this area. Despite the general nature of the map containing these locations, the data nevertheless indicate that the zones are elongate and have variable orientations. The extent of these additional zones appear to be similar to that determined for the above mentioned zone, that is they are on the order of several hundred metres in strike length. Thus, collectively, this

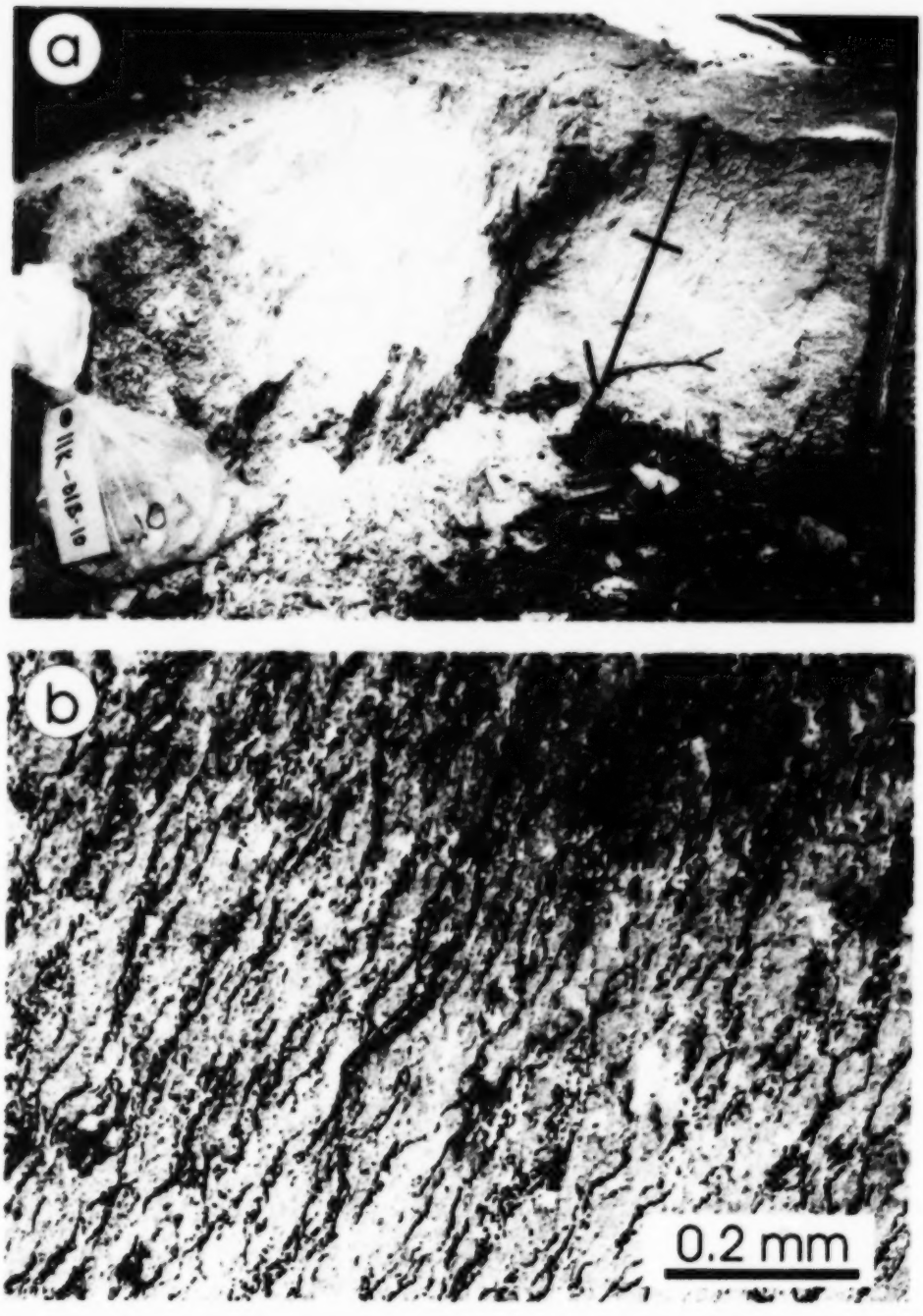


Figure 2. (a) Outcrop photo showing pyrophyllite-rich altered volcanic rock in northern part of the map area (see inset of Fig. 1). Orientation of the schistose fabric is indicated by the inclined cleavage symbol. Note hammer on right side for scale. (b) Photomicrograph of pyrophyllite-rich rock showing well-developed fabric. Dark lines defining fabric are altered oxides (i.e., rutile, leucoxene) and carbonate, whereas intervening areas are pyrophyllite and quartz.

Table 1. Electron microprobe analysis of typical altered volcanic rock, Cape Breton Island.

Sample	CB-2002	CB-2002	CB-2002	CB-2002	CB-2002	CB-2002	CB-2002
Mineral	pyrophyllite	pyrophyllite	pyrophyllite	pyrophyllite	diaspore	diaspore	diaspore
Point	1	3	4	7	2	17	22
SiO_2	65.02	67.00	67.50	67.55	0.12	0.57	1.10
Al_2O_3	30.71	28.39	28.27	27.89	83.95	82.63	81.95
FeO	-	0.12	0.20	0.09	-	0.09	0.06
MnO	0.05	0.07	0.13	-	-	0.25	0.05
CaO	0.25	0.09	-	0.13	0.07	-	0.02
Na_2O	0.12	0.07	0.01	0.11	-	0.00	0.01
Total	96.31	95.97	96.51	96.48	84.45	83.55	83.30

indicates that there is significant tonnage potential for the pyrophyllite.

4.2 Petrography and Mineralogy of the Altered Felsic Volcanic Rocks

The altered felsic volcanics are dominated by fine-grained phases that included clots of xenomorphic silica with subgrain development, abundant phyllosilicates, altered oxides (i.e. leucoxene, rutile), and carbonate. There is a well-developed planar fabric throughout (Figure 2b) and uniform distribution of the mineral phases.

Given the very fine-grained nature and similarity of alteration minerals in volcanic rocks (i.e. various clay phases), detailed methods of mineral identification have been used to characterize the samples. In the first instance a sample of the altered volcanic rock was prepared as a polished section for examination with the electron microprobe using combined imaging and mineral analysis. Collectively, the imaging and analysis indicates the presence of quartz, pyrophyllite, diaspore and carbonate (Table 1). In addition, imaging analysis (Figure 3a) indicates the very fine-grained nature of the phases, generally several tens of microns, and their intimate intergrowth. The well-developed fabric seen in the hand sample was also seen during image analysis (e.g. Figure 3b,3c) where all the minerals were observed to be aligned parallel to this fabric, thus the minerals were either synchronous with or pre-dated fabric development.

In the second method of analysis, three samples of altered volcanics that had been crushed to

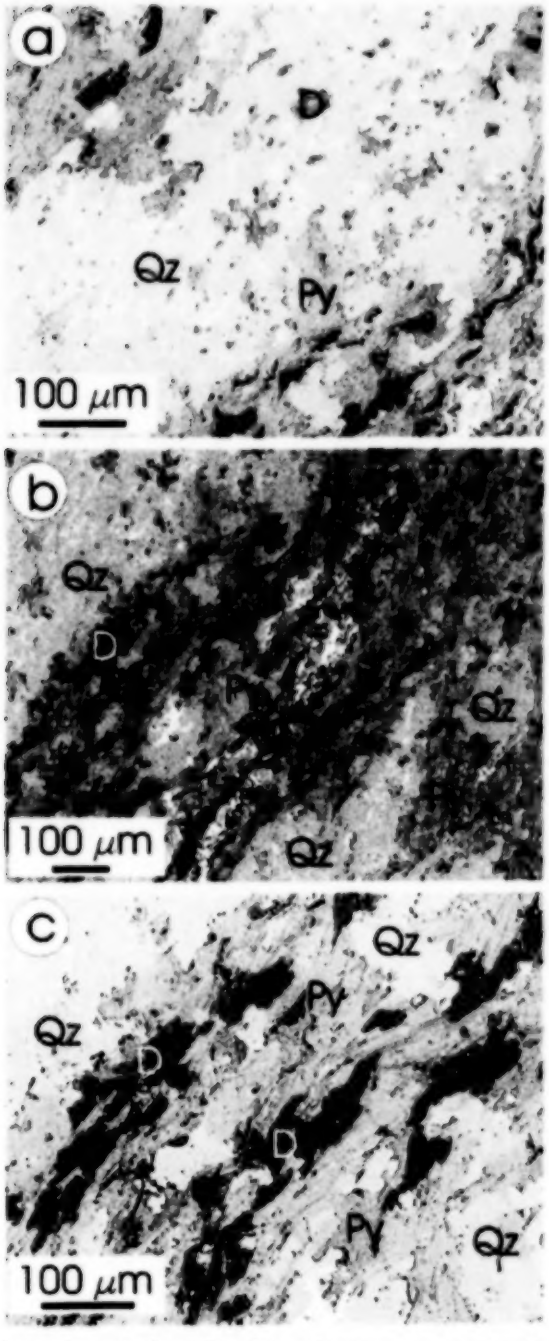
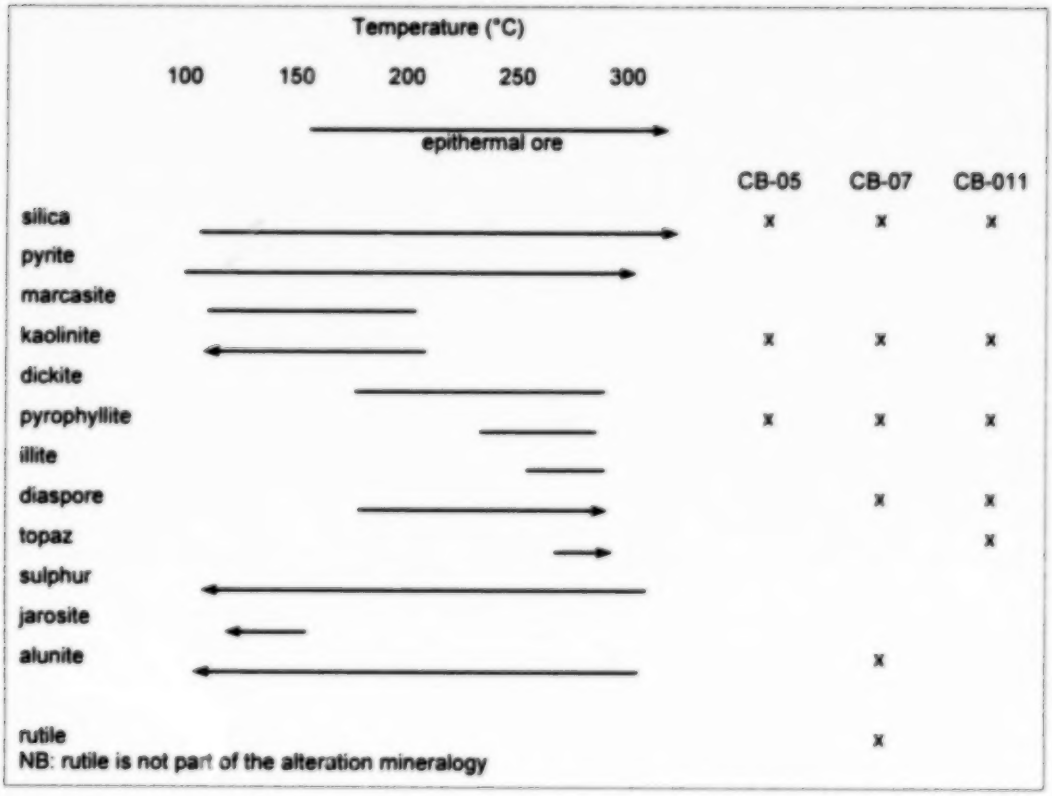


Figure 3. *Back scattered electron images of sample in Figure 3b illustrating the mineralogy of the altered volcanic rock. In the images the mineral with the lower average atomic number is dark and the one with the highest average atomic number is brightest. Abbreviations are as follows: pyrophyllite (Py), diaspore (D) and quartz (Qz). The bright material defining a NE-fabric in 6b is rutile (i.e., Ti- rich), hence its brightness in the imaging.*

Table 2. *X-ray analysis of selected altered volcanic rock.*



<200 mesh for whole rock chemical analysis, were analyzed using Philips Rietveld software at Queen's University, Kingston, Ontario. In this method, the X-ray lines recorded from the sample are used to determine the presence of minerals and their abundance can be quantified. The work is still in progress and not yet completed; however, initial results of the analysis of three samples are summarized in Table 2, where they are compared to the minerals present in high-sulphidization epithermal environments (White and Hedenquist, 1995). It is evident that there is a strong similarity of the mineralogy present in the altered volcanics of Coxheath to those expected in epithermal environments related to high-sulphidization systems.

4.3 Chemistry of the Altered Volcanic Rocks

Chemical analysis of sixteen altered volcanic rocks are presented in Table 3. Note that except for samples CB-02, CB-05, CB-13 and CB-14, all of these samples come from the area in

Table 3. Major oxide and trace element geochemistry of altered volcanic rocks (Late Proterozoic), Coxheath.

Sample	CB-01	CB-02	CB-05	CB-06	CB-07	CB-08	CB-09	CB-10	CB-11	CB-13
Major elements (wt. %)										
SiO_2	73.26	83.77	84.09	71.71	71.16	70.70	69.94	71.82	67.02	72.73
TiO_2	0.736	0.256	0.405	0.688	0.664	0.764	0.690	0.649	0.428	0.266
Al_2O_3	20.26	11.78	11.82	20.39	21.73	21.81	22.50	21.07	25.11	14.34
Fe_2O_3	0.2	0.26	0.26	0.14	0.35	0.53	0.31	0.21	0.15	1.68
MnO	0.001	0.003	0.001	<.001	<.001	<.001	<.001	<.001	0.007	0.013
MgO	0.02	<0.01	<0.01	0.01	0.01	0.01	0.02	0.01	0.02	2.06
CaO	0.12	0.11	0.05	0.55	0.08	0.06	0.07	0.06	0.15	0.44
Na_2O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
K_2O	0.01	0.02	0.06	0.03	0.06	0.03	0.04	0.01	0.01	3.93
P_2O_5	0.162	0.072	0.061	0.19	0.295	0.213	0.232	0.126	0.177	0.058
L.O.I.	4.13	2.4	2.13	4.65	4.84	5.54	4.72	4.33	5.42	3.69
Totals	98.9	98.67	98.88	98.36	99.19	99.66	98.52	98.3	98.71	99.48
Trace elements (ppm)										
V	80	36	57	79	72	81	75	72	74	54
Cr	12	14	22	9	9	10	12	14	7	8
Co	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zr	366	192	214	300	419	394	375	265	320	237
Ba	1448	1241	299	1521	519	70	545	<25	<25	314
La	46	21	37	63	44	51	36	64	69	25
Nd	36	22	28	41	30	38	22	36	45	13
Ni	4	5	6	6	6	6	6	4	7	6
Cu	11	13	11	10	20	18	16	10	10	<5
Zn	20	20	22	20	19	19	19	19	18	250
Ga	19	17	14	19	19	18	19	18	21	17
Rb	<2	3	4	2	<2	<2	<2	2	<2	159
Sr	763	419	368	859	2387	1634	1737	430	742	39
Y	19	14	15	19	22	17	16	17	13	41
Nb	8	6	6	8	8	8	8	7	8	10
Pb	49	38	25	48	87	75	84	39	57	41
Th	9	<2	19	17	5	8	8	17	24	8
U	<1	2	4	<1	<1	<1	<1	2	<1	5

Analysis done at the regional XRF facility, St. Mary's University, Halifax

Table 3. continued

Sample	CB-14	CB-15	CB-16	CB-17	CB-18	CB-19
Major elements (wt. %)						
SiO_2	69.87	69.67	75.24	66.55	71.13	71.18
TiO_2	0.266	0.637	0.563	0.569	0.524	0.630
Al_2O_3	10.68	24.1	18.61	19.48	22.02	21.85
Fe_2O_3	1.6	0.11	0.18	0.18	0.17	0.18
MnO	.073	<.001	<.001	.001	<.001	<.001
MgO	0.21	0.02	0.02	0.02	0.02	0.01
CaO	5.4	0.09	0.11	0.05	0.06	0.07
Na_2O	4.06	<0.01	<0,01	0.03	<0.01	<0.01
K_2O	1.8	0.03	0.07	0.04	0.02	0.02
P_2O_5	0.059	0.217	0.255	0.187	0.156	0.162
L.O.I.	4.11	4.78	4.06	5.1	5.23	4.84
Totals	98.13	99.65	99.11	92.21	99.32	98.94
Trace elements (ppm)						
V	31	79	65	93	68	68
Cr	21	9	4	4	6	6
Co	<5	<5	<5	<5	<5	<5
Zr	164	335	340	422	310	325
Ba	433	166	278	33077	7304	1497
La	30	36	57	52	50	65
Nd	32	34	45	96	48	57
Ni	<3	4	6	<3	6	6
Cu	6	12	12	12	13	10
Zn	35	17	19	21	19	18
Ga	7	21	23	20	22	20
Rb	56	<2	<2	<2	<2	<2
Sr	172	1139	1325	2238	1017	737
Y	35	10	16	11	11	15
Nb	9	6	7	9	8	8
Pb	19	68	72	294	168	99
Th	4	10	12	10	21	19
U	5	<1	<1	<1	<1	<1

Analysis done at the regional XRF facility, St. Mary's University, Halifax

Figure 1 where the NSDNR trenching was undertaken, which is the former quarry site and northward extension of the quarry mineralization zone. Most of the samples are similar with respect to their degree of argillic alteration, but some differences are noted: (1) samples CB-02 and CB-05 contain some quartz veins, (2) 11K01B-13 contains a potassium-rich mineral phase, probably white mica based on the wt. % K_2O, and (3) 11K01B-14 contains albite and carbonate. The following points are noted regarding the major and minor element chemistry of these rocks (Table 3) and, for comparative purposes, they have been plotted with unaltered volcanic rocks of the Coxheath suite, grouped into basalts and andesites and rhyolites (after Barr et al., 1996) in Figure 4. (1) These rocks have high silica values typical of rhyolites, with the exception of two samples with >80 wt. % SiO_2 due to the presence of quartz veins. (2) Most samples show extreme enrichment in alumina with 18 to 25 wt. % Al_2O_3, which compares to 12-15 wt. % Al_2O_3 in the unaltered rhyolites. The exceptions to this are the two rocks that have the quartz vein material that has diluted the alumina content and two samples which are not as pervasively altered. (3) The altered rocks are all extremely depleted in alkalies, with both potassium and sodium stripped in all but two samples. (4) The abundances of iron, magnesium and calcium are also very low. (5) The abundances of titanium and phosphorus are similar to unaltered felsic volcanic rocks in the area, thus these elements may be used as indicators of the primary chemistry of the altered rocks (see below).

In the Al_2O_3 versus SiO_2 plot the chemistry of representative muscovite and pyrophyllite are plotted on the binary diagram along with a tie line joining quartz and pyrophyllite. The altered volcanic rocks plot along this line at mixtures of 70 to 90% by weight of pyrophyllite. Thus, the analyzed samples are clearly dominated by this mineral phase. The lack of potassium in these rocks indicate that secondary white mica is not present in these samples (see K_2O+Na_2O versus SiO_2 plot in Figure 4).

Twelve samples of pyrophyllite ore were collected at the former quarry site and its northward extension (Figure 1). These samples have an average composition of 70.83% SiO_2, 21.57% Al_2O_3, 0.26% Fe_2O_3, 0.03% K_2O, and less than the detection limit of 0.01% Na_2O_3 in all cases except one.

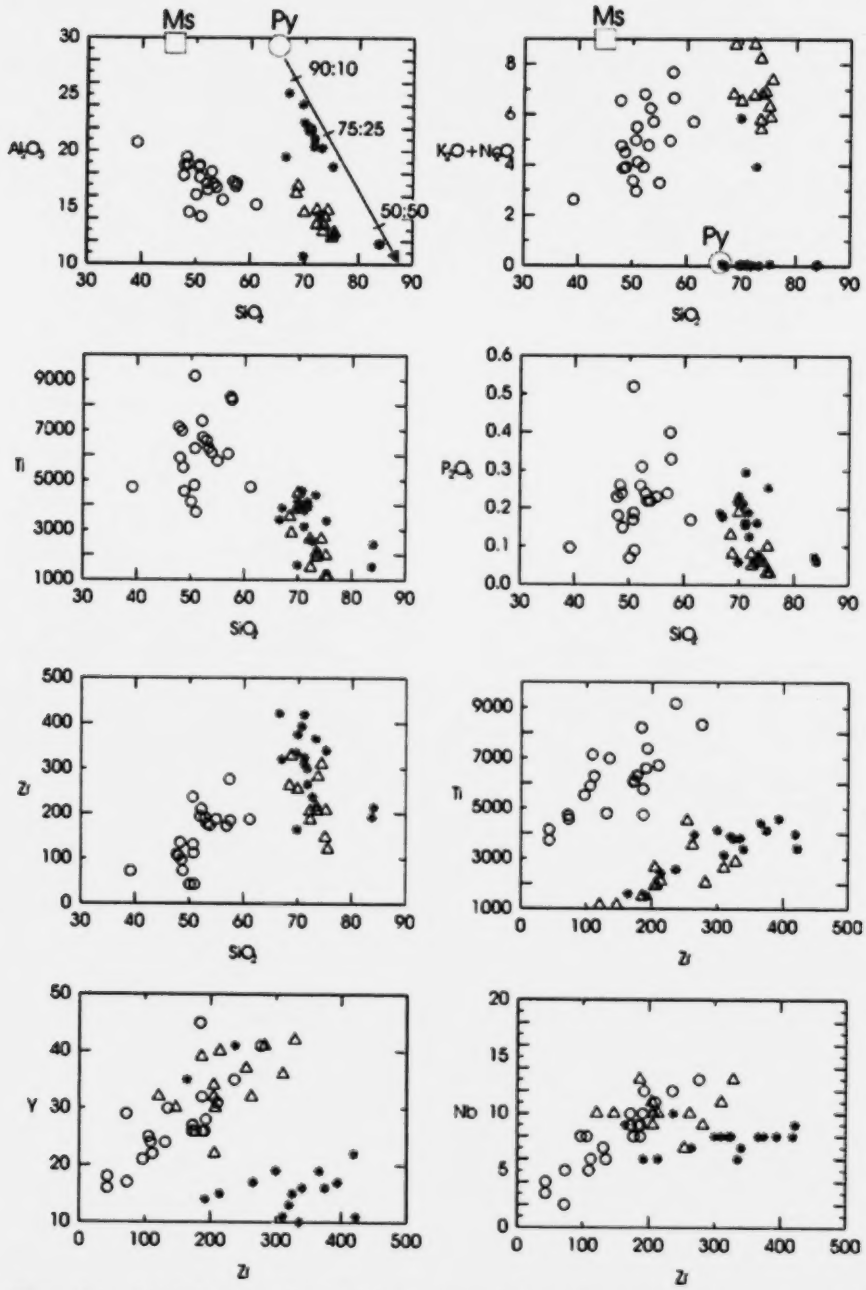


Figure 4. *Binary element plots for suite of samples from the pyrophyllite-rich volcanic rocks (*) compared to the data base of Barr et al. (1996) for andesite (o) and rhyolite (Δ). The abbreviations in the top plots are for muscovite (Ms) and pyrophyllite (Py). The tie line with numbers relates to the proportions of pyrophyllite and quartz mixtures and indicate that the whole rock samples in this study have mixtures of about 90:10 to 50:50 of these mineral phases. The arrow on the tie line points to 100% SiO_2 or quartz. Note that in the Pb versus Ti/Ar plot one sample is enriched in Pb (to 294 ppm).*

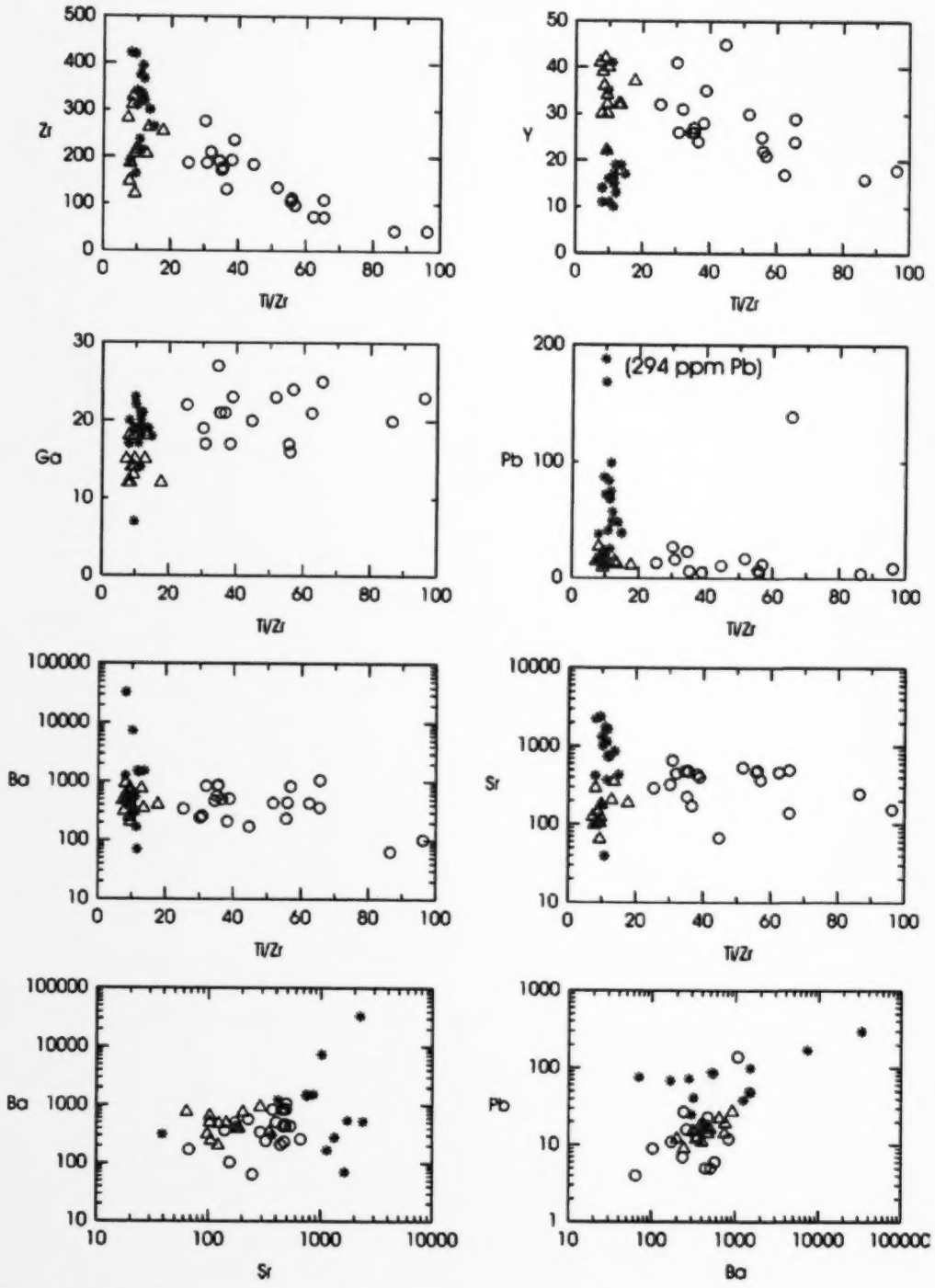


Figure 4. *continued*

Comparison of these chemical results with typical analysis of pyrophyllite presented by Harben and Kuzvart (1997) indicate that the Cape Breton ore is typically higher in SiO_2 than US or Newfoundland ore and lower than South Korean ore. It has lower Al_2O_3 levels than US and Newfoundland ores, but contains higher amounts than many South Korean ores. In fact the Al_2O_3 levels are typically mid-range compared with other ores produced around the world. Fe_2O_3 levels are much lower than US , Newfoundland and most other pyrophyllite produced in countries such as South Korea or Japan. This would be important in tile applications where iron acts as a colouring agent when clays are fired. Similarly K_2O and Na_2O levels are equal or better than typical values world wide. These elements can also effect the firing temperature and rheological properties of tiles.

5.0 Discussion and Conclusions

In the foregoing sections we have discussed the salient aspects of the geological setting, petrology, mineralogy and alteration, and nature of mineralization in two disparate systems, one a porphyry type environment and the other an epithermal, high-sulphidization system. We suggest here that the relationship between the diorite-hosted, porphyry style Cu-Mo-Au mineralization and the occurrence of extensive zones of argillically altered rocks (i.e. volcanics containing pyrophyllite, alunite, topaz, diaspore, and kaolinite) in the overlying coeval volcanics is considered more than coincidental.

For example, we highlight the presence of celsian (Ba-rich) feldspar in the altered diorite, barite in late veins of the Coxheath area, and the anomalous content of up to 3% barium in the pyrophyllite rocks. Thus, we suggest the linking of these two disparate systems into a single deposit model based on the present knowledge of porphyry-epithermal systems. It has been suggested for some time that there is a continuum from the underlying coeval intrusive rocks to the petrogenetically related volcanic carapace (e.g. Sillitoe, 1973). More detailed studies of mineralized districts over the past few decades have made more clear the relationship between the magmatic source fluids and extensively altered and mineralized zones in the high-level epithermal environments (e.g. Hayba et al., 1985; White and Hedenquist, 1995). The alteration zones in these environments are distinguished based on their mineralogy such that low- and

high-sulphidization systems are recognized and are considered to reflect the contribution of magmatic sulphur, originating as SO_4, from a shallow magmatic system. The mineral assemblage identified in the pyrophyllite-rich zones are indicative of a high-sulphidization system and suggests, therefore, an underlying magmatic source for sulphur. This conclusion suggests that there may also be potential for base and precious mineralization and the relative proximity of the Coxheath mineralized environment further supports this model.

As noted by Lynch and Ortega (1997), the features of the Coxheath Cu-Au-Mo system bear many similarities to the porphyry gold deposit type discussed by Sillitoe (1993). In addition, we have shown that the occurrence of altered volcanic rocks in the petrogenetically related volcanic carapace can be interpreted in the context of a high sulphidization system. The present distribution of the plutonic and volcanic rocks in this area would suggest that this system has been tilted to expose a porphyry-epithermal system of Precambrian age. Although additional work is clearly required to refine this model, it is felt that the geological features of the two systems have been documented sufficiently to support the model presented and is testament to the occurrence of and preservation of high-level hydrothermal systems back into the Late Proterozoic. Further evidence for this model and the potential for precious metal mineralization is the occurrence of other high-sulphidization systems of Late Proterozoic age in the Avalon Zone of the Appalachians (e.g. Dubé et al., 1998; O'Brien et al., 1999).

In addition to significant precious- and base-metal potential, the Coxheath area holds potential for small to moderate sized, high quality pyrophyllite deposits. Typical pyrophyllite operations produce in the order of tens of thousand of tonnes a year. As with many industrial minerals, a major hurdle is to find a market for the ore. Additional deposits of pyrophyllite need to be located in the Coxheath area. Market research and an aggressive search to find a market might result in a small-scale mining and processing operation. Further geological mapping, sampling and testing are required.

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